Effects of Petroleum Pollution and the Remediation Attempts in Ogoniland, Rivers State, Nigeria: A Review

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Abstract: Ogoniland has been suffering from severe environmental devastation occasioned by petroleum pollution since the discovery and exploitation for over five decades. This has brought ill-health and untold hardship to the Ogoni people as the farmlands and water were destroyed. The situation is exacerbated by the uncertainties hanging around hope of complete clean-up and prevention of further spills with consequent public health risks implications. The overall effect has been worsened due to neglect by the stakeholders and relevant authorities. This enormous environmental devastation provoked the Ogoni youths into violent protest and clashes with the security agents which led to the stoppage of activities by Shell Petroleum Development Company (SPDC) in 1992. The situation compelled the relevant authorities to seek a way of attending to the massive environmental devastation in Ogoniland. In Ogoni environments, soil and water are still severely polluted despite several claims of clean-up. Large volume of this pollution occurs as a result of human error with abandoned dilapidated flow stations/oil transport lines, illegal drilling/refining of crude oil and deliberate destruction of oil transport lines. There is deployment of inappropriate remediation strategies and abandoning without the needed monitoring. This review re-evaluates the cumulative impacts of crude oil pollution on the Ogoni environments and the people, different clean-up attempts, strategies and the present state of the environment. Generally, work progress at the remediation sites has been judged to be very slow. However, excavation of the affected soil, subsequent transfer to the bio-cell treatment sites and backfilling of treated soil is ongoing at the moment. Therefore, it is hope that the present remediation strategy will completely clean-up Ogoni environments of crude oil pollution, restore life and hope to Ogoni people while appropriate measures are put in place to prevent further oil spills in Ogoniland.

Keywords: Petroleum, Ecosystem, Ogoniland, Pollution, Remediation.

INTRODUCTION

Ogoniland is among the oil producing communities in the Niger Delta, River State of Nigeria which covers 1,000 km^2 at latitude 4.05 and 4.20 North and longitude 7.10 and 7.30 East (Nkpaa, *et al.*, 2016; 2017; UNEP, 2011). According to the 2006 national census, the population of Ogoni people is about 832,000 with four Local Government Areas, named: Eleme, Gokana, Khana, and Tai (Balouga, 2009; UNEP, 2011). The Ogoniland has both riverine and upland communities, hence majority of Ogoni people are generally fishermen. However, there is also an increased interest in crop production to ensure food security of Ogoni people (UNEP, 2011). This drives the remediation efforts focusing mostly on the terrestrial environment to rescue and recover more lands for crop production (Johnson and Ronald, 2015).

Ogoniland is divinely blessed with numerous water bodies flowing through different creeks and harbouring abundance natural resources typified by the crude oil (Amnesty International, 2015). It has been the site of exploration of crude oil with consequent exploitation of the environment by the oil industries since the late 1950s. There are poorly documented histories of severely environmental contamination and devastation occasioned by oil well fires, gas flaring/venting and numerous records of oil spills (UNEP, 2011). There are also proofs of attempt at recovering the Ogoni environments from crude oil pollution (UNEP, 2011; Jaja and Obuah, 2019). To this, different techniques; which could be physical, chemical or biological, depending on the type of environment have been applied (Lim *et al*., 2016). The effectiveness of some of these technologies, as employed in the Ogoniland could not be ascertained as many of them were inappropriately deployed or abandoned without the needed monitoring (Amnesty International *et al*., 2020).

Oil exploration as a source of Environmental pollution in Ogoniland

The dominant crude oil exploration company in Ogoniland is the Shell Petroleum Development Company (SPDC). This company started its activities in 1958, managing a total of 96 oil wells representing nine oil fields on the stream (Nenibarini and Franklin, 2016). There is increase in both national and global demand for crude oil being the principal source of energy and wealth (Ikhimiukor and Nneji, 2013). This almost complete dependence on petroleum for wealth and as a source of energy and fuel puts the Ogoniland and her people at great risk due to the consequent contamination of the environments.

The crude oil pollution in Ogoniland has originated from legal and illegal oil drilling and refining activities which involved huge network of oil transport pipelines (Olof and Jonas, 2013; UNEP, 2011). Illegal refining of crude oil has also immensely contributed to severe hydrocarbon pollution of Ogoniland (UNEP, 2011). It was reported that an increased illegal oil refining in Bodo West, Bonny LGA resulted in the environmental devastation with consequent destruction of mangrove vegetation (UNEP, 2011). There was emergence of groups in the region that deliberately destroy oil transport lines, resulting in more pollution to the environment (Amnesty International, 2019). The absolute disregard for the health effects of the people living therein exacerbated the already dire situation of the Ogoni community (Kvenvolden and Cooper, 2003; Bayat *et al*., 2015).

Many years after cessation of crude oil exploration by the SPDC in some fields, there are still traces of crude oil pollution in Ogoni environments, particularly the aquatic environments (UNEP, 2011). Network of oil transport pipelines convey about 150,000 barrels of crude oil daily through Ogoni Shell's export terminal at Bonny Island (Kelechukwu and Ruth, 2020). These pipelines leak as a result of corrosion or act of sabotage, abandoned dilapidated flow stations and other illegal oil-related activities ensured continuous pollution of the environment (Figure 1).

Figure 1: Abandoned Flow station at K/Dere, in Gokana LGA. Source: Michael Uwemedimo/cmapping.net

Human exposure to crude oil

The major routes through which the Ogoni people are exposed to crude oil pollution include body contact with contaminated soil or water, inhalation/respiration and ingestion of contaminant. Exposure through bodily contact; either from water or soil is very common (Ordinioha and Brisibe, 2013). People always have direct body contact with water during bathing, washing or fishing (UNEP, 2011; Barron, 2012).

Those that till the soil also make body contact with contaminated soil and also inhale volatile hydrocarbons (UNEP, 2011; Owhonda, 2016; Sylvia, 2019). The people in Ogoniland are also exposed to vapourized hydrocarbon evaporating from already contaminated environment (Kampa, 2008; Sylvia, 2019). Studies indicated that 35 million metric tons of CO_2, methane gas and Volatile Organic Compounds (VOCs) are released yearly through gas flaring in the Niger Delta (Nriagu, 2011; Okhumode, 2017). Consumption of crude oil contaminated water and sea foods such as oyster, shrimps and lobsters are the major ways through which crude oil get into human digestive system (Gohlke *et al*., 2011; Barron, 2012).

Effects of crude oil pollution on water meant for human consumption

The first obvious target of crude oil pollution of aquatic environment is the destruction of the aesthetic nature of the water. The Ogoni surface water bodies usually appeared dark brown and cloudy as a result of oil sheen on the water surface with a characteristic foul hydrocarbon odour. The biochemical reactions in water, decay of dead aquatic plants and anoxygenic metabolism of the pollutant by anaerobic organism's results in obnoxious smell, rendering it completely unappealing for human uses (Frank and Boisa, 2018). The water is not good for recreational activities, washing dishes, laundry and certainly not good for drinking (UNEP, 2011; Lindén and Pålsson, 2013; Nganje, *et al*., 2015; Davies and Abolude, 2016; Frank, and Boisa, 2018). Studies found extractable petroleum hydrocarbons in surface waters says up to 7420 microgram per litre and benzene up to 9000 microgram per litre of water are 900 times more than the WHO recommendation for drinking (Okhumode, 2017). Studies also indicated that these surface water bodies are systematically polluted with different petro-compounds like benzene, toulene, ethylbenezene and xylene (BTEX), Polycyclic Aromatic Hydrocarbons (PAHs) among other petroleum pollutants, extending down the shallow wells linking aquifers, which are major sources of groundwater (Ndubuisi and Asia, 2007; Godson *et al*., 2009). The consequence is that Ogoni people lack portable water for drinking and other domestic uses as people need to travel long distance to get portable water (UNEP, 2011; Okhumode, 2017).

Effects of Crude oil Pollution on Aquatic Biota

Surface water bodies with visible oil sheen covering the surface are usually not good habitat for aquatic macro and micro-organisms (Frank and Boisa, 2018). The thin layer of oil that covers the water surface hinders light and oxygen penetration into the water body. This affects chemical and biological processes as obligate aerobes are harmed while photosynthetic activities especially at the benthic regions are seriously disrupted (Fent, 2004; Labud *et al*., 2007; Alrumman *et al*., 2015; Deng and Linda, 2018). The photosynthetic aquatic plants and other primary producers in the ecosystem are grossly affected, setting up destructive competition and lack of food within the aquatic ecosystem as food chain is disrupted (Frank and Boisa, 2018). The BTEX compounds are highly volatile and are primary constituents of light crudes (ATSDR, 2009). They are easily miscible with water, a feat that facilitates their penetration into aerobic organisms living in the water. These compounds are highly toxic to organisms they are exposed to (Gary, 2011).

Severe crude oil pollution of aquatic environments in Ogoniland has caused poor fish yield as many of the fishes either die from starvation or die of direct crude oil effects (Langangen *et al*., 2017). Exposure to crude oil causes spoilage of fish eggs resulting in delayed, premature or no hatching of the eggs (Blackburn *et al*., 2014; Langangen *et al*., 2017) Also, poor development and stunted growth may occur in larvae and embryos exposed to pollution (Sørensen *et al*., 2017). Consequently, survived species have all migrated away from their localities to other water bodies where the water is cleaner and free from severe hydrocarbon pollution (UNEP, 2011). This has drastically reduced fish harvest and by implication, affects protein supply as well as the economy of the Ogoni people (Okhumode, 2017).

Effects of crude oil pollutants on Farmlands activities

When farmlands polluted with crude oil are left without remediation, the microbial communities and biological activities within the soil surface at the affected sites are grossly affected due to the crude oil toxicity (Digha *et al*., 2017). The oil seals up the pores on the soil surface, rendering the soil impermeable to the essential factors needed for soil organisms to survive. The outcome of this is complete blockage of air exchange through soil surface pores and poor penetration of light, water and nutrients into the sub-soil (Frank and Boisa, 2018). Ultimately, the soil fertility is grossly affected as aerobic microbes involved in breaking down of organic matter and turning them into essential nutrients for crops utilization were starved (Abii and Nwosu, 2009; Digha *et al*., 2017). Anaerobic condition in the soil increases the solubility of certain elements like Iron and Manganese that are potentially photo-toxic elements (Abii and Nwosu, 2009). When these elements are absorbed by plants, stunted leaves or plant defoliation can result (Digha *et al*., 2017).

Moreover, crude oil spillage on the soil inhibits plant seeds germination by covering the endosperm of the seed thereby inhibiting water and oxygen penetration into the seed, resulting in the death of the seed (Abii and Nwosu, 2009). Crude oil can also coat the root tissues of root crops, resulting in the decay of crops and reduced overall crop yield. Such affected crops involved cassava and yam which are part of the major crops produce of Ogoni people (UNEP, 2011). High concentration of crude oil in the rhizosphere reduces the soil pH, thereby creating acidic condition within the plant's root region which encourage fungal colonization and eventually root rots (Owhonda, 2016; Odiyi *et al*., 2020).

When polluted farmland is left unattended to, the oil will leached down into the sub-soil polluting the underground water while some are washed away via surface run-off into other farmlands and neighbouring water bodies (UNEP 2011). Oil spills also results in bush fires which destroy vegetation and create film layer on the soil (Owhonda, 2016). The PAHs are compounds with numerous benzene rings. As major constituents of crude oil, PAH compounds are usually incriminated in partial combustion of hydrocarbon, a feat which enhances their toxicity (Waller, 1994). Smoke produced during the burning of PAH, which contains partially burnt hydrocarbon, hinders the plant's photosynthetic activities when deposited on healthy leaves and stems of plants by blocking the stomata on the leaves and the lenticels on the stems (Zeiger, 2006; UNEP 2011; Owhonda, 2016).

Studies have it that severe crude oil pollution of Ogoni farmlands resulted in serious soil degradation which adversely affected agricultural activities and declined food production (Digha *et al*., 2017). The poor food production, even for subsistence use directly affects the socio-economic condition of the Ogoni people (Boele *et al*., 2001) and consequently influences the general life of a typical Ogoni indigene who depends wholly on what he gets from the land for survival (Joel, 2019).

Health implications of Crude oil pollution in Ogoniland

Health implications of the crude oil pollution in Ogoniland is that those who live or work in communities with history of gas flaring are extremely susceptible to cancer of the lung, asthmatic cough and eye irritation (Ndubisi and Asia, 2007; Okhumode, 2017). Ethyl benzene and xylenes act as neurotoxins while benzene is a known human carcinogen (Ordinioha and Brisibe, 2013). Hence, fishermen who are constantly exposed to BTEX compounds are also vulnerable to neurotic diseases and cancer (Gary, 2011; Waller, 1994).

Other documented ailments associated with inhalation of vapourized hydrocarbon include dizziness, shortness of breath, throat irritation, headache, confusion and mental health impairment (Carrasco *et al*., 2007; ATSDR, 2009; Aguilera, *et al.,* 2010). Those that have made direct and consistence body contact with the crude oil are vulnerable to skin diseases such as oedema, blisters, dermatitis, inflammation, cancer and rashes of the skin (ATSDR, 2009; Aguilera *et al.,* 2010; Major and Wang 2012). Also, consumption of contaminated water and hydrocarbon contaminated aquatic foods has made diarrhea and related gastrointestinal issues a common occurrence among the villagers especially in children (Bosch, 2003; Gema *et al*., 2007; Okhumode, 2017).

Acid rain effect

Gas flaring discharges hazardous particles into the atmosphere as it is a common practice within the entire Niger Delta (Buzcu-Guven and Harriss, 2012; Emam, 2016). This practice releases partially burnt or unburnt hydrocarbon substances into the atmosphere, causing serious air pollution with ensuing severe environmental and public health implications (Emam, 2016). Partially burnt hydrocarbons in the atmosphere mix up with rain, reducing pH of the water to 4.98-5.15 range thereby causing acid effect (Nwankwo and Ogagarue, 2011). Roofs of houses in Ogoniland are conspicuously seen in brown colouration as a result of corrosion caused by acid rain (Efe, 2010; Ejelonu *et al*., 2011). This makes roofs of houses to get old quickly as perforated and leaking house roofs are common occurrence within the Ogoni communities (Okhumode, 2017).

Figure 2: Roofs of houses in brown colouration as a result of Acid rain. Source: www.unep.org

Life in Ogoniland

Life in Ogoniland has become very tough especially for those that lost farmlands, homes and other sources of livelihood to oil spillage (Frank and Boisa, 2018). Some people deserted their ancestral homes, friendly beaches and vegetation (Kelechukwu and Ruth, 2020). The consequence is the drastic decline of overall quality of life of the Ogoni people with ensuing enormous psychological strain; provoking worries, hopelessness, dissatisfaction, frustration, discomfort, anger and hatred among the inhabitants of the local communities (Jerome *et al.,* 2016).

In most cases, the psychological issue results in stress and fatigue; aging quickly and shorter life expectancy (Loureiro *et al.*, 2005; Rajagopalan, 2010; Kelechukwu and Ruth, 2020).

Indigenes of Ogoniland are predominantly famers (fish farmers and crop producers). These sources of livelihood have been taken away by oil pollution as crude oil destroys water bodies and farmlands. The failure to avail new sources of livelihood to Ogoni people has resulted in pushing many indigenes into criminal tendencies in order to survive (UNEP, 2011). Hence, there is rapid increase in illegal oil bunkering and other illegal oil-related activities. (Amnesty International *et al*., 2020).

Implementation of the United Nations Environmental Program's Recommendations

In 2006, the local and international organizations pressurized the Nigerian Government to invite United Nations Environmental Programme on environmental assessment in Ogoniland (UNEP, 2011). The report of this assessment was published in 2011 as the key findings include extensive hydrocarbon contamination of Ogoni environments with unnecessary delay in the clean-up response. Part of the recommendations include complete overhaul of remediation approach by the SPDC, which resulted in the establishment of the Environmental Restoration Authority (UNEP, 2011).

In an attempt to implement the UNEP recommendations, the Federal Government of Nigeria established Hydrocarbon Pollution and Remediation Project (HYPREP) to oversee the clean-up operations (UNEP, 2014). This HYPREP trained Ogoni indigenous scientists on environmental preservation professions such as the management of contaminated site assessment, clean-up assessment, clean-up of contaminated sites and field work techniques (UNEP, 2014).

Remediation Attempts of Crude Oil-Polluted Ogoni environments

i Solidification of excavated contaminated soil for construction purpose

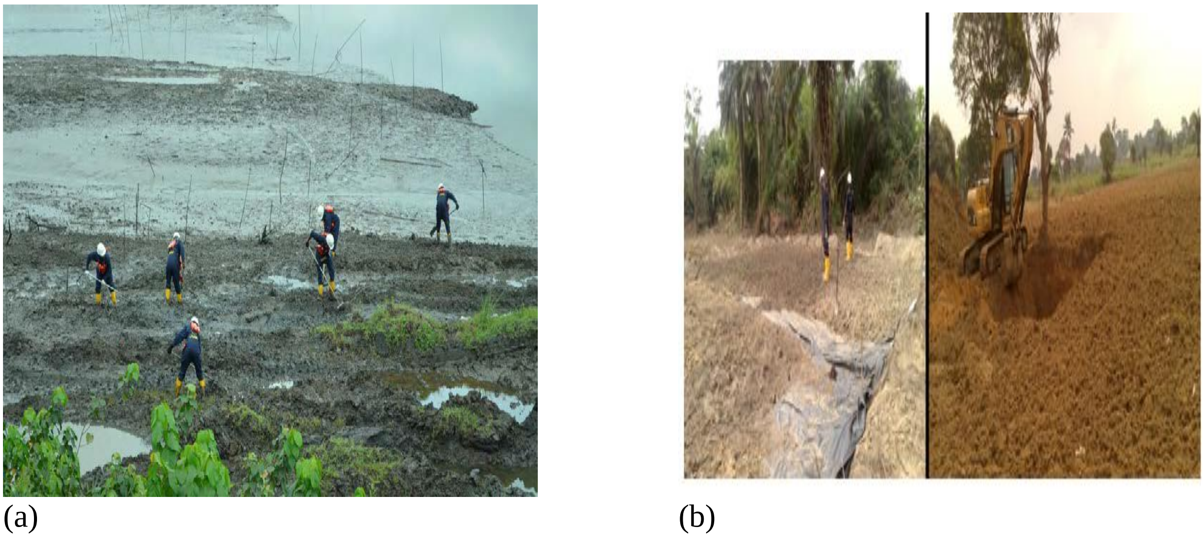
This is a physical remediation protocol which involved mixing the contaminated soil with cement for construction purpose (Johnson and Olukorede, 2014). This will reduce the soil contaminants to an acceptable level that will not cause harm to humans. The process is done using chemical neutralizer and incineration especially in areas with minimum contaminations (Yedil *et al*., 2020). It is among the earliest strategies employed in reclaiming the Ogoni environments from crude oil pollution by SDPC. The soil is deeply excavated to the range of 6m-10m as in the case of Ejama Ebubu in Eleme LGA where 40,000 soil crete bricks were produced (Mmom and Igbuku, 2015). Such strategy brought joy to the community but was immediately abandoned because the deep trench created while dredging the soil became a site that required attention as erosion brought back the contaminants that were previously removed (Amnesty International, 2019).

ii Remediation by Enhance Natural Attenuation (RENA)

This is the most commonly used remediation strategy in Ogoniland otherwise known as the land farming (Ebuehi *et al*., 2005; Onifade *et al*., 2007; Wegwu *et al*., 2010). The RENA strategy follows the principle of bioremediation in which hydrocarbons are spontaneously degraded by indigenous microorganisms (Bento *et al*., 2005; Wegwu *et al*., 2010). It is usually an active reaction of microbes to the pollutants that have devastated their immediate habitat and threatened their very existence (David, 2018). In an attempt to escape the ruinous effects of the pollutants, microbes create a unique means of turning the harmful pollutants into a useful delicacy (Abatenh *et al*., 2017; David, 2018). In the process, toxic pollutants are transformed into less toxic/nontoxic compound or are completely broken down to their elemental forms (Shweta and Pratyoosh, 2020).

The procedure entails addition of stimulants on the soil that was initially drained from crude oil contaminants. The stimulant is usually synthetic fertilizers which supplement the nutritional requirements of the microbes in the affected sites as they degrade the pollutants. The next step under RENA strategy is tillage of the soil to enhance aeration of the soil and encourage aerobic microbial processes needed for hydrocarbon biodegradation (Chen *et al*., 2007). Tilling the soil also ensures thorough mixture of the added nutrients to make them available to the degrading microbes (UNEP, 2011; Orji *et al*., 2012).

Remediation by Enhance Natural Attenuation strategy has been reported as one of the most viable and effective microbial-based remediation protocol especially in cleaning-up crude oil polluted soil (Wegwu *et al*., 2010). It was almost the only remediation strategy employed in Ogoniland for soil recovery as observed by UNEP in Bodo creek and B-Dere, Gokhana LGA (UNEP, 2011) (Figure 3). In this strategy, the collaborative efforts (Patowary *et al*., 2016) of different species of indigenous microbes (Singh *et al*., 2012; Joutey *et al*., 2013; Mouna *et al*., 2018); bacteria, fungi (Mishra *et al*., 2001; Bender and Phillips, 2004; Singh, 2006) and even algae (Aditi *et al*., 2015; Nithiya *et al*., 2018; Pankaj *et al*., 2019; Diana *et al*., 2020) with hydrocarbon-degrading abilities, such as the ability to secrete degradative enzymes, biosurfactants and growth factors (Helia and Philip, 2003; Elumalai *et al*., 2017; El-Sheshtawi *et al*., 2017), are stimulated into degrading an array of hydrocarbon pollutant (Wang *et* al., 2011; Wasoh *et al*., 2019). Hence, degradation commences immediately the indigenous organisms are able to survive the effects of the spillage, adapt and grow exponentially in the contaminated environment. Thus, if well-stimulated and aerated, RENA remediation strategy has the ability to completely clean-up crude oil contaminated soil environment of different components of hydrocarbon. For instance, short and long chains hydrocarbons, PAHs and even non-hydrocarbon compounds including trace metals; many of which are hydrophobic and very difficult to biologically degrade are susceptible to degradation (Joutey *et al*., 2013; Ghosal *et al*., 2016; Elumalai *et al*., 2017; Mouna *et al*., 2018). In a particular study where RENA was applied in recovering crude oil-polluted site, culturable hydrocarbon utilizing bacteria from the genera of *Achromobacter, Alcaligenes, Azospirillus, Bacillus, Lysinibacillus, Ochrobactrum, Proteus, and Pusillimonas* were found as the active degraders of total petroleum hydrocarbon (Chioma *et al*., 2017).



(a) (b)

Figure 3: Land Farming in (a) Bodo creek and (b) in B-Dere, Ogoniland. Source: unep.org.

This remediation process has not been a successful story in Ogoniland due to challenges faced. Firstly, it can only be applied on the terrestrial environment since addition of chemical stimulant like NPK will further contaminate the water and render it completely unusable. Secondly, only about 15-20cm of the soil is dug out and mixed with the stimulated top soil, with the excuse that the soil is clayey and would not permit leaching of oil deeper into the subsoil (UNEP, 2011). However, studies by UNEP indicated that crude oil pollutants, even on the acclaimed remediated sites had already leached deeper beyond 5m and if recovery of only 15-20cm into the subsoil is assured under RENA strategy, the safety of the underground water is not guaranteed. The UNEP report went on to note that RENA approach was ineffective because of Oxygen circulation which is very poor beyond 1m depth (UNEP, 2011).

Very importantly, RENA technique depends on the availability of hydrocarbon-degrading microbes to spontaneously degrade the contaminants. On this, it is worthy to note that some forms of hydrocarbon are too toxic or unyielding to microbial degradation (UNEP, 2011). Hence, RENA technique fails if there are no hydrocarbon-degrading microbes or when the predominant forms of hydrocarbon on the site are too toxic for the indigenous microbes. This makes the entire process even more unreliable considering the enormous time needed for the available species of these microbes to adapt and start degradation especially in the case of large volume of oil spillage (Ebuehi *et al*., 2005; Johnson and Ronald, 2015).

iii **Scooping/Draining and Disposal**

This physical remediation strategy involved draining the soil to remove as much oil as possible on the soil surface. It also involves siphoning of severely contaminated small non-flowing water bodies and discharging the contaminated water into a constructed containment pit or plastic tank known as sump where the contaminated water is further treated before final disposal (Rosalie *et al*., 2020). The sumps are usually covered and regularly monitored to avoid overflow and consequent flooding of the contaminant into unpolluted sites (Anum *et al*., 2020). In the case of Ogoniland, it was observed that the scooped contaminated water was usually disposed indiscriminately (Figure 4) where it easily becomes source of pollution to other sites (HYPREP, 2021). Heavily polluted water bodies are usually considered for draining and because the water contains large volume of the contaminant, the physical and chemical properties of the soil at the dump site are always severely affected. However, the severity of the impact depends on the type of soil. On dry sandy soil, the volatile components usually evaporate almost immediately the contaminated water is disposed, reducing the volume of the contamination and causing less damage to the soil. Such cannot be said of wet clay soil (UNEP, 2011). Heavy crude oil deposit on wet clay soil remains on the soil for a long time, interrupting with the penetration of water, air and nutrient into the soil, causing harm to soil microbial community and compromising the quality of the soil (UNEP, 2011). Moreover, the few constructed sumps were poorly done and abandoned afterwards (Amnesty International *et al*., 2020).

Figure 4: Indiscriminately disposed contaminant. Source: Isaac Harry/cmapping.net, 2020.

iv Biocell Technology

This technology involves construction of large dumpster in concrete cement or with large plastic tanks. Crude oil polluted-soil is then loaded into the tank. Aerobic microbial activities are stimulated through aeration as microbes degrade the contaminant. Moisture and nutrients are added to enhance microbial degradation of the hydrocarbon adsorbed to soil particles. Drainage pipes are usually connected from the biocell to the sump to drain contaminated water (NFESC, 2017). The floor and walls of biocells constructed with cement material are usually sealed with water-proof material to avoid leaching of the contaminant into the subsoil (HYPREP, 2021). Treated soil is usually returned to where it was excavated (Amnesty International *et al*., 2020).

Like the RENA strategy, the Biocell protocol also depends on the activities of the indigenous microbial consortium that are stimulated to carry out the degradation of the pollutants (Patowary *et al*., 2016). However, unlike the land farming that is done in open ground, the biocell protocol is restricted in constructed equipment, which is advantageous as it prevents escape of the contaminant via leaching or surface run-off.

As observed by Amnesty International/Environmental Right Action scientists, the biocell treatment at some sites in parts of Gokana LGA was judged to have failed as the systems were badly constructed. Polythene material of very low quality and in some cases, rice and cement bags were used for biocell floor and walls instead of the High Density Polythene (HDP) material, resulting in biocell with compromised structure (Amnesty International *et al*., 2020). There was no addition of nutrients or periodic aeration of the system to stimulate the autochthonous microbes into degradation of the pollutants. Also, the drainage sumps; mostly plastic tanks seem to be too small to contain large volume of contaminated water from the biocell and the few sites constructed with concrete materials are in serious bad shape and are not also covered (Amnesty International *et al*., 2020). When it rains, contaminants spilled over the sumps, spreading and polluting the environment the more.

(a) (b)

Figure 5: Poorly constructed and abandoned biocell drainage sumps. Source: Amnesty international.org

v Biopile Technology

Biopile technology involves collection of crude oil-contaminated soil and forming the soil into piles on a flat soil surface (BERD, 1996). The area is surrounded with sandbags to avoid escape of the pollutant via run-off (USEPA, 2017). The base of the biocell (soil surface) is usually sealed with an impermeable material to avoid or reduce leaching of pollutant down the subsurface environment (Egbo *et al*., 2018). A leachate collection system may also be constructed under the base for collection of the leached pollutant especially when addition of enough moisture is anticipated. The contaminated piles are covered with membrane to protect it from downpour and also prevent the escape of volatile contaminants into the air via dust.

Biopile technology, like the biocell technique also operates based on biodegradation. Nutrients such as nitrogen and phosphorus are added while water is made available if needed, all to facilitate microbial degradation of the contaminants (USEPA, 2017; Amnesty International *et al*., 2020).

Biopile technique is an improved version of RENA approach but unlike the RENA approach that needs periodic mixing of the soil, the biopile treatment is static; the soil is not occasionally mixed to avail moisture, oxygen and nutrient to the degrading organisms and this may result in treated soils that are not uniform. However, the technique through its base sealing prevents loss of the contaminants via leaching (BERD, 1996). It encourages also biodegradation by autochthonous anaerobic microorganisms since the piles are not aerated (Egbo *et al*., 2018). The biopile treatment at Ogoniland was also judged to have failed because of the poor construction of the system and lack of the required monitoring (Amnesty International *et al*., 2020).

(a) (b)

Figure 6: (a) Badly constructed and abandoned Biopile. (b) Incomplete Biopile construction with sandbags used as side walls seen already ripped off, compromising the strength of the biocell wall. Sources: Isaac Harry/cmapping.net, 2020.

Poor planning and lack of commitment on the part of the Federal government and of course the oil company culminated in operational faults and failure. The Covid 19 pandemic lockdown of 2020 was on hand to provide an immediate excuse for workers on the site to completely abandon the remediation program. Hence, it has become very difficult to ascertain the effectiveness or otherwise of the afore mentioned remediation protocols being applied in the clean-up of crude oil polluted Ogoni environments (Amnesty International *et al*., 2020). For instance, the biocell and biopile systems which depend wholly on microbial actions on the pollutants operate on chance. The contractors do not know any of the microbial species involved in the hydrocarbon degradation, there was no routine monitoring, no peristaltic pumps to send nutrients to the degrading microbes in the biocell, hence, nutritional stimulation to improve the activities of the degrading microbes was also lacking (Amnesty International *et al*., 2020).

Meanwhile, the sabotage and oil theft continues with ensuing new spills and pollution of previously uncontaminated sites. Moreover, the pollutant continues its journey down the subsoil (over 8m) beyond the region documented by UNEP in 2011. Most water bodies are still very much polluted. Even areas classified as having been satisfactorily remediated are still heavily polluted since the works were abandoned and were never completed (Amnesty International *et al*., 2020).

(a) (b) (c)

Figure 7: (a) An excavated trench, showing layer of oil on the water surface in a dredged pit. Source: Isaac Harry/cmapping.net, 2020. (b) Poorly placed and abandoned containment boom at Nkpoku-Bomu since 2015. Source: ENI photograph. (c) Abandoned biopile remediation lot. Source: Isaac Harry/cmapping.net

The Report of HYPREP activities in 2021

Despite the position of HYPREP that 70% of clean-up of Ogoniland has been completed, the fact remains that Ogoni environments are still very far from being rescued of crude oil pollution (CSLAC, 2020). Illegal oil refinery operators and saboteurs are always on hand to ensure that the situation is aggravated (Amnesty International *et al*., 2020). However, the activities of HYPREP, beginning from January 2021 have tried to proffer solutions to the established concerns that form the basis of this review. For instance, to curb illegal drilling/refining of crude oil and intentional destruction of oil pipelines, it was generally believed that improving the living conditions of the Ogoni people by creating more livelihoods would be very helpful in engaging the locals and steering the youths away from the criminal activities. On this, HYPREP started the training of Ogoni women and youths in Civic Education, Agribusiness and Entrepreneurial Skills and then setting up Cooperative societies for the trained women and youths (HYPREP, 2021). To minimize ill-health associated with consumption of crude oil-contaminated water, HYPREP engaged with the State Ministry of Water Resources to rehabilitate existing water facilities in Ogoniland and construct new ones in areas where there are none in other to ensure potable water for Ogoni people in accordance with the UNEP recommendation (HYPREP, 2021). To ensure the success of the present remediation strategies, the first important step taken was for the Government, via the HYPREP to assume full responsibility of project ownership. Hence, HYPREP usually carried out on-the-spot assessment of contractors' performance at the remediation sites to ensure that workers stick to the specifications of the contracts in accordance with the international best practice as enshrined in the terms of the contract agreement (HYPREP, 2021).

Part of UNEP recommendations mandated SPDC to periodically conduct comprehensive review of its assets and develop a wide-ranging decommissioning plan (UNEP, 2011). In the HYPREP progress reports of March 2021, there has been no mention of the status of SPDC oilfield infrastructures in Ogoniland. By implication, there are still no immediate plans on the maintenance of oilfield facilities or decommissioning of aged ones.

On the issue of massive environmental devastation occasioned by multiple oil spills, remediation activities in parts of Ogoniland resumed following ease of Covid 19 lockdown. Presently, work is going on in almost all the sites, with a different remediation approach. The contractors resumed with full mechanical remediation protocol of excavation, *ex situ* treatment and backfilling of remediated soil. The soil is usually dredged up at severely impacted sites using heavy duty bulldozer to the depth of 5m and taken to an offsite location for treatment (HYPREP, 2021). This protocol is very quick but very expensive. The cost of evacuating the dug up crude oil polluted soil and transporting it to the dump or treatment site and bringing the soil back to the point of excavation after treatment is not cost effective (Ding *et al*., 2020).

Figure 8: Excavated soil taken to treatment site. Source: hyprep.gov.ng.

The choice of excavation and evacuation to an offsite location; a quick remediation strategy, was adopted probably to minimize the risk of continuous movement of the contaminant into the subsoil if treatment is to be done *in situ* (Rosalie *et al*., 2020) or to hasten the clean-up exercise following the aggravation of the environmental situation as the sites were abandoned during the Covid 19 lockdown.

Black High Density Polythene (HDP) material can be seen covering the floor of the treatment sites while the surroundings encased with the impermeable HDP materials (Rosalie *et al*., 2020) to avoid the contaminants escaping into the subsoil or to unpolluted locations (HYPREP, 2021). Treatment of excavated crude oil polluted soil usually involves washing the soil with chemical, which usually provides very fast result as hydrocarbons are substantially removed from the soil within very minimal time. The chemicals are usually organic solvents like ethanol, ethyl acetate or acetone but mixed with water (Khodadoust *et al*., 1999; Diphare and Muzenda, 2014). The effectiveness of these organic solvents and of course the process itself is enhanced with the inclusion of surfactants like sodium dodecyl sulfate (SDS), saponin or rhamnolipid (Ding *et al*., 2020). This strategy is very effective as heavy metals are also washed alongside the hydrocarbons (Urum and Pekdemir, 2004). However, procuring the solvents and the surfactants makes the process more expensive (Ding *et al*., 2020). Treated soil samples are taken to accredited laboratory to confirm substantial decrease in the levels of Total Petroleum Hydrocarbon before it is returned to backfill the trenches from where it was taken.

Figure 9: Treated soil ready for evacuation by the local sand dredger. Source: hyprep.gov.ng

CONCLUSION

Studies indicated a serious environmental devastation occasioned by extensive crude oil pollution of Ogoniland. The soil, water and air have all been severely polluted, resulting in different health challenges caused by intake/inhalation of or contact with crude oil/components. The sources of livelihood have also been affected as crop and fish farming are greatly disrupted. The present review has revealed that ten years after the UNEP`s report, various clean-up attempts and strategies applied are yet to achieve much. The effectiveness of the remediation strategies, as applied on the impacted sites could not be ascertained as they were abandoned half way. Meanwhile, leakages from abandoned dilapidated flow stations and from illegal artisanal refining activities ensured continuous pollution and aggravation of already dire environmental situation. However, this review gathered from the HYPREP report of an active environmental remediation on-going in Ogoniland. The review also ascertained of efforts aimed at improving the living conditions of the Ogoni people, new opportunities are provided with new sources of livelihoods availed to Ogoni people. It is hoped that the present remediation strategy will completely clean-up Ogoni environments of crude oil pollution, restore life and hope to Ogoni people in a hygienic and healthy environment while appropriate measures are put in place to prevent further oil spills in Ogoniland.

REFERENCES

Abatenh, E., Gizaw, B., Tsegaye, Z. and Wassie, M. (2017). The Role of Microorganisms in Bioremediation: A Review. *Open Journal of Environmental Biology*, 1(1), 38-46.

Abii, T. A. and Nwosu, P. C. (2009). The effects of oil spillage on the soil of Eleme in Rivers State of the Nigger Delta Area of Nigerian. *Research Journal of the Environment*, 1, 316-320.

Aditi, P., Kumar, G. and Suneetha, V. (2015). The role of algae in degradation of petroleum wastes, A study. *Journal of Chemical and Pharmaceutical Research,* 7(1), 499-503.

Agency for Toxic Substances Disease Registry, ATSDR. (2009). Interaction Profile for Benzene, Toluene, Ethylbenzene, and Xylenes (BTEX). US Department of Health and Human Services, Atlanta, GA. Accessed on 16th June, 2019 from: www.atsdr.cdc.gov/interactionprofiles.

Aguilera, F., Méndez, J., Pásaro, E. and Laffon, B. (2010). Review on the effects of exposure to spilled oils on human health. *Journal of Applied Toxicology*, 30(4), 291-301.

Alrumman, S. A., Standing, D. B. and Paton, G. I. (2015). Effects of hydrocarbon contamination on soil microbial community and enzyme activity. *Journal of King Saud University – Science*, 27, 31–41.

Amnesty International (2015). No Progress: *An Evaluation of the Implementation of UNEP's Environmental Assessment of Ogoniland: Three Years On.* Environmental Rights Action/Friends of the Earth Nigeria, Centre for the Environment, Human Rights and Development and Friends of the Earth Europe. Accessed on 9th September, 2019 from: https://www.amnesty.org.uk/files/unep_briefing_2014.

Amnesty International. (2019). Negligence in the Niger Delta: decoding Shell and ENI's poor record on oil spills. Accessed on 8th Mar, 2021 from: www.amnesty.org.

Amnesty International, Friends of the Earth Europe, Friends of the Earth Europe Netherlands/ Milleudefensie and Friends of the Earth Nigeria/Environmental Right Action. (2020). No clean-up, No Justice: an evaluation of the implementation of UNEP's Environmental assessment of Ogoniland, nine years on. Accessed on 4th Mar, 2021 from: www.armnesty.org/AFR44/2514.

Anum, A. A., Ishaq, M., Tariq, S., Qudratullah, K., Jianbo, Z. and Zeyi, L. (2020). Remediation Methods of Crude Oil Contaminated Soil. *World Journal of Agriculture and Soil Science*, 4(3), 1-8,

Balouga, J. (2009). The Niger Delta: Defusing the Time Bomb. International Association for Energy Economics. Accessed on 9th September, 2019 from: https://www.iaee.org/documents/newsletterarticles/109balouga.

Barron, M. G. (2012). Ecological impacts of the deep-water horizon oil spill: Implications for immunotoxicity. *Toxicologic Pathology*, 40(2), 315-320.

Battelle Environmental Restoration Department (BERD). (1996). Biopile Design and Construction Manual. Prepared for Naval Facilities Engineering Service Center (NFESC). Technical Memorandum. pp. 1-2.

Bayat, Z., Hassanshahian, M. and Cappello, S. (2015). Immobilization of microbes for bioremediation of crude oil Polluted environments: A mini review. *The Open Microbiological Journal*, 9, 48-54.

Bender, J. and Phillips, P. (2004). Microbial mats for multiple applications in aquaculture and bioremediation. *Bioresources Technology*, 94, 229-238.

Bento, F. M., Camargo, F. A., Okeke, B. C., & Frankenberger, W. T. (2005). Comparative Bioremediation of Soils Contaminated with Diesel Oil by Natural Attenuation, Biostimulation and Bioaugmentation. *Bioresource Technology*, 96(9), 1049-1055.

Blackburn, M., Mazzacano, C. A. S., Fallon, C. and Black, S. H. (2014) Oil in our oceans: a review of the impacts of oil spills on marine invertebrates. Portland, Oregon, The Xerces Society for Invertebrate Conservation. P. 152.

Boele, R., Fabig, H. and Wheeler, D. (2001). Shell, Nigeria and the Ogoni. A Study in Unsustainable Development: The Story of Shell, Nigeria and the Ogoni People-Environment, Economy, Relationships: Conflict and Prospects for Resolution. *Sustainable Development*, 9, 74–86.

Bosch, X. (2003). Exposure to oil spill has detrimental effect on clean-up workers´ health. *Lancet*, 361, 147.

Buzcu-Guven, B. and Harriss, R. (2012). Extent, Impacts and Remedies of Global Gas Flaring and Venting. *Carbon Management*, 3, 95–108.

Carrasco, J. M., Perez-Gomez, B. and Lope, V. (2007). Health-related quality of life and mental health in the medium-term aftermath of the prestige oil spills in Galiza (Spain): A cross-sectional study. *BMC Public Health*, 17(7), 245.

Chen, T. Y., Kao, C. M., Chai, C. T., Chen, C. Y. and Lin, C. E. (2007). Application of oxygen-releasing material to enhance in situ aerobic bioremediation. *Proceedings of the 3rd World Scientific and Engineering Academy and Society: International Conference on Mathematical Biology and Ecology*, 1-5.

Chioma, B. C., Christopher, C. A. and Evan, M. F. (2017). Shift in microbial group during remediation by enhanced natural attenuation (RENA) of a crude oil-impacted soil: a case study of Ikarama Community, Bayelsa, Nigeria. *3 Biotechnology*, 7, 152.

CSLAC (Civil Society Legislative Advocacy Centre; 2020). HYPREP's 70% Completion Claim – Unravelling the true state of the remediation project. *Environment and Conservation*. Acessed on 28th Mar, 2021 from: www.cislacnigeria.net.

David, N. O. (2018). Application of Biological Methods in the Remediation of Oil Polluted Environment in Nigeria. *Journal of Advances in Biology and Biotechnology*, 17(4), 1-10.

Davies, O. and Abolude, D. (2016). Polycyclic aromatic hydrocarbons (PAHs) of surface water from Oburun Lake, Niger Delta, Nigeria. *Applied Science Report*, 13, 20-24.

Deng, Y. and Linda A. (2018). Assessing the Impact of Oil Spills on Marine Organisms. *Journal of Oceanography and Marine Research*, 6(1), 1-7.

Diana, P., Ana, C. R., Leonel, P. and Tiago, V. (2020). Microalgae Water Bioremediation: Trends and Hot Topics. *Applied Sciences*, 10, 1886.

Digha, O., Ambah B. and Jacob, E. N. (2017). The effects of crude oil spillage on farmland in Gokana Local Government Area of Rivers State. *European Journal of Basic and Applied Sciences*, 4(1), 2059-3058.

Ding, X., Anum, A. A., Ishaq, M., Tariq, S. and Qudratullah, K. (2020). Remediation Methods of Crude Oil Contaminated Soil. *World Journal of Agriculture and Soil Science*, 4(3), 1-8.

Diphare, M. and Muzenda, E. (2014). Remediation of oil contaminated soils: A review. In: *International Conference on Chemical Integrated Waste Management and Environmental Engineering*, Johannesburg. pp. 180-184.

Ebuehi, O., Abibo, I., Shekwolo, P., Sigismund, K., Adoki, A., and Okoro, I. (2005). Remediation of Crude Oil Contaminated Soil by Enhanced Natural Attenuation Technique. *Journal of Applied Science and Environmental Management*, 9(1), 103-106.

Efe, S. I. (2010) Spatial Variation in Acid and Some Heavy Metal Composition of Rainwater Harvesting in the Oil-Producing Region of Nigeria. *National Hazards*, 55, 307–319.

Egbo, W. M., Egbo M. E., Beredugo, Y. E., Goldie, J. and Alagoa, E. E. (2018). Bioremediation: A Strategic and Sustainable Technique for the Remediation of the Hydrocarbon Polluted Environment of the Niger Delta. *International Journal of Geography and Environmental Management*, 4(4), 1-10.

Ejelonu, B. C. Adeleke, B. B. Ololade, I. O. and Adegbuyi, O. (2011). The Chemistry of Rainwater Samples Collected Within Utorogu-Oil Producing Community in Niger Delta, Nigeria II. European Journal of Scientific Research, 58, 189–203.

El-Sheshtawy, H. S., Khalil1, N. M. Ahmed, W. and Nabila, A. A. (2017). Enhancement the Bioremediation of Crude Oil by Nanoparticle and Biosurfactants. *Egyptian Journal of Chemistry*, 60(5), 835 – 848.

Elumalai, P., Parthipan, P., Karthikeyan, O. P. and Rajasekar, A. (2017). Enzyme-mediated biodegradation of long-chain n-alkanes (C_{32} and C_{40}) by thermophilic bacteria. *3 Biotechnology*, 7, 116.

Emam, E. A. (2016). Environmental Pollution and Measurement of Gas Flaring. *International Journal of Innovative Research Science and Engineering Technology*, 2, 252–262.

Fent, K. (2004). Ecotoxicological effects at contaminated sites. *Toxicology*, 205, 223–240.

Frank, O and Boisa, N. (2018). The effect of crude oil spill on the surface water of the Lower Niger Delta (Sombriero River). *Journal of Industrial and Environmental Chemistry*, 2(2) 19-24.

Gary, S. (2011). Effects of Oil in the Environment. In: Mervin, F. (1st ed). Oil Spill Science and Technology. Gulf Professional Publishing. pp. 985-1024.

Gema, R., Jan, P. Z. and Isabel, I. M. (2007). Health Effects of Exposure to Oil Spills. *Arch Bronconeumol*, 43(11). 628-35.

Ghosal, D., Ghosh, S., Dutta, T. K. and Ahn, Y. (2016). Current state of knowledge in microbial degradation of polycyclic aromatic hydrocarbons (PAHs): A review. *Frontiers in Microbiology*, **7,** 1369.

Godson, A. R., Sridhar, M. K. and Bamgboye, E. A. (2009). Environmental Risk Factors and Health Outcomes in Selected Communities of the Niger Delta Area, Nigeria. *Perspective Public Health*, 129, 183–191.

Gohlke, J. M., Doke, D., Tipre, M., Leader, M. and Fitzgerald, T. (2011). A review of seafood safety after the Deepwater Horizon blowout. *Environmental Health Perspectives*, 119, 1062-1069.

Helia, R. and Phillip, C. W. (2003). Alcohol dehydrogenases from thermophilic and hyperthermophilic archaea and bacteria. *Federation of European Microbiological Societies Microbiology*, 27, (2003) 593-616.

Hydrocarbon Pollution Remediation Project (HYPREP). (2021). Report on HYPREP activities for the month of January 2021: status of phase 1, batch 1 and batch 2 remediation project. Retrieved on 16th Mar, 2021 from: www.hyprep.gov.ng.

Ikhimiukor, O. O. and Nneji, L. M. (2013). The Review of the use of Microorganisms in Biodegradation of Crude Oil Spill: Challenges and Prospects. *Researcher*, 5(12), 5–7.

Jaja, J. M. and Obuah, E. (2019). The Politics of the Ogoni Clean-up: Challenges and Prospect. *African Researchers and Reviewer*, 13(3), 101-113.

Jerome, N., Emilia, A. U., Ibanga, E. and Godwin, E. (2016). Health Risks Associated with Oil Pollution in the Niger Delta, Nigeria. *International Journal of Environmental Research and Public Health*, 13, 1-23.

Joel, O. A. (2019). In Nigeria's polluted Ogoniland, signs of a cleanup. Accessed on 24th Feb, 2021 from: https://phys.org/news/2019-03-nigeria-polluted-ogoniland-cleanup.

Johnson, R. O. and Olukorede M. O. (2014). Oil Contaminated Soil as Potential Applicable Material in Civil

Engineering Construction. *Journal of Environment and Earth Science*, 4(10), 1-14.

Johnson, O. and Ronald, L. (2015). Remediation by Enhanced Natural Attenuation, RENA: A beneficial strategy for polyaromatic hydrocarbon degradation and Agrifood Production. *Proceedings of the World Congress on New Technologies*, 183, 1-11.

Joutey, T., Bahafid, W., Sayel, H. and ElGhachtouli, N. (2013). Biodegradation: involved microorganisms and genetically engineered microorganisms. In: *Biodegradation–Life of Science*, Chap.11, eds by Chamy, R. and Rosenkranz, F. Rijeka, Intech Publications. doi:10.5772/56194.

Kampa, M. (2008). Human health effects of air pollution. *Environmental Pollution*, 151(2), 362–367.

Kelechukwu, I. and Ruth, O. (2020). Nigeria's silent killer: The deadly price of oil. Accessed on 8th Mar, 2021 from: www.theafricareport.com.

Khodadoust, A. P., Suidan, M. T., Acheson, C. M. and Brenner, R. C. (1999). Solvent extraction of pentachlorophenol from contaminated soils using water-ethanol mixtures. *Chemosphere*, 38(11), 2681-2693.

Kvenvolden, K. A., Cooper, C. K. (2003). Natural seepage of crude oil into the Marine Environment. *Geo-Marine Letters*, 23(3-4), 140 – 146.

Labud, V., Garcia, C. and Hernandez, T. (2007). Effect of hydrocarbon pollution on the microbial properties of a sandy and a clay soil. *Chemosphere*, 66, 1863–1871.

Langangen, Ø., Olsen, E., Stige, L. C., Ohlberger, J. and Yaragina, N. A. (2017). The effects of oil spills on marine fish: Implications of spatial variation in natural mortality. *Maritime Pollution Bulletin*, 119,102-109.

Lim, M. W., Lau, E. V. and Poh, P. E. (2016). A comprehensive guide of remediation technologies for oil contaminated soil-present works and future directions. *Marine Pollution Bulletin*, http://dx.doi.org/10.1016/j.marpolbul.2016.04.023.

Lindén, O. and Pålsson, J. (2013). Oil contamination in ogoniland, Niger Delta. *Ambio*, 42, 685–701.

Loureiro, M. L., Ribas, A., López, E. and Ojea, E. (2005). Estimated costs and admissible claims linked to the Prestige oil spill. *Ecological Economics*, 59, 48-63.

Major, D. N. and Wang, H. (2012). How public health impact is addressed: A retrospective view on three different oil spills. *Toxicological and Environmental Chemistry*, 94, 442-467.

Mishra, S., Jyot, J., Kuhad, R. C. and Lal, B. (2001) In situ bioremediation potential of an oily sludge degrading bacterial consortium. *Current Microbiology*, 43.

Mmom, P. and Igbuku, A. (2015). Challenges and Prospect of Environmental Remediation/Restoration in Niger Delta of Nigeria: The Case of Ogoniland. *Journal of Energy Technologies and Policy*, 5(1), 1-7.

Mouna, M., Simone, C., Yasmine, S., Atef, J. and Ameur, C. (2018). Microbial Bioremediation of Petroleum Hydrocarbon–Contaminated Marine Environments. *Recent Insights in Petroleum Science and Engineering*, 2-27.

Ndubuisi, O. L. and Asia, I. O. (2007). Environmental Pollution in Oil Producing Areas of the Niger Delta Basin, Nigeria: Empirical Assessment of Trends and People's Perception. *Environmental Research Journal*, 1, 18–26.

Nenibarini, Z. and Franklin, B.G. T. (2016). Assessment of Asymmetric Mangrove Restoration Trials in Ogoniland, Niger Delta, Nigeria: Lessons for Future Intervention. *Ecological Restoration*, 34(3), 2-14.

Nganje, T. N., Hursthouse, A. S., Edet, A., Stirling, D. and Adamu, C. (2015). Hydrochemistry of surface water and groundwater in the shale bedrock, Cross River basin and Niger Delta region, Nigeria. *Applied Water Science Journal*. Retrieved on 25th August, 2020 from: http://dx.doi.org/10.1007/s13201-015- 0308-9.

Nithiya, A., Shreeshivadasan, C., Hesam, K., Sathiabama, T., Norazli, O. and Noor, S. N. (2018). Treatment of Wastewater Using Seaweed: A Review. *International Journal of Environmental Research and Public Health*, 15, 2851.

Nkpaa, K. W., Patrick-Iwuanyanwu, K. C. and Wegwu, M. O. (2016). Health risk assessment of hazardous metals for population via consumption of seafood from Ogoniland, Rivers State, Nigeria; a case study of Kaa, B-Dere, and Bodo City. Environmental Monitoring Assessment, 188(1), 9.

Nkpaa K. W., Onyeso, G. I. and Achugasim, O. (2017). Heavy metals levels in shellfish from Bodo City and B-Dere, Ogoniland, Rivers State, Nigeria, and evaluation of possible health risks to consumers. Sustainable Water Resources Management, 3(1), 83–91.

Nriagu, J. (2011). Oil Industry and the Health of Communities in the Niger Delta of Nigeria. In: Jerome, O. N. (Ed). *Encyclopedia of Environmental Health*. Burlington, Elsevier. pp. 240–250.

Nwankwo, C. and Ogagarue, D. (2011). Effects of Gas Flaring On Surface and Groundwaters in Delta State Nigeria. *Journal of Geology and Mining Research*, 3, 131–136.

Odiyi, B. O., Giwa, G. O., Abiya, S. E. and Babatunde, O. S. (2020). Effects of Crude Oil Pollution on the Morphology, Growth and Heavy Metal Content of Maize (*Zea mays* Linn.) *Journal of Applied Science and Environmental Management*, 24(1), 119-125.

Okhumode, H. Y. (2017). Addressing Environmental Health Problems in Ogoniland through Implementation of United Nations Environment Program Recommendations: Environmental Management Strategies. Environments 2017, 4, 28, 1-18.

Olof, L. and Jonas, P. (2013). Oil Contamination in Ogoniland, Niger Delta. *AMBIO- Royal Swedish Academy of Sciences*, 42, 685–701.

Onifade, A., Abubakar, F., & Ekundayo, F. (2007). Bioremediation Of Crude Oil Polluted Soil In The Niger Delta Area Of Nigeria Using Enhanced Natural Attenuation. *Research Journal of Applied Sciences*, 2(4), 498-504.

Ordinioha, B. and Brisibe, S. (2013). The human health implications of crude oil spills in the Niger delta, Nigeria: An interpretation of published studies. *Journal of the Nigeria Medical Association*, 54(1), 1-8.

Orji, F. A., Ibiene, A. A. and Ugbogu, O. C. (2012). Petroleum Hydrocarbon Pollution of Mangrove Swamps: The Promises of Remediation by Enhanced Natural Attenuation. *American Journal of Agricultural and Biological Sciences*, 7(2), 207-216.

Owhonda, I. (2016). Review of United Nations Environmental Programme (UNEP). Report on the Environmental Assessment of Ogoniland. pp. 1-30. Accessed on 28th May, 2019. From:

researchgate.net/publication/323015407.

Pankaj, K. G., Shashi, R. and Sanjay, K. G. (2019). Phycoremediation of Petroleum Hydrocarbon-Polluted Sites: Application, Challenges, and Future Prospects. In: S. K. Gupta, F. Bux (eds.). *Application of Microalgae in Wastewater Treatment*. Switzerland, Springer Nature. Pp. 1-17.

Patowary, K., Rupshikha, P., Mohan, C. K. and Suresh, D. (2016). Development of an Efficient Bacterial Consortium for the Potential Remediation of Hydrocarbons from Contaminated Sites. *Frontiers in Microbiology*, 1-14.

Rajagopalan, V. K. (2010). Health concerns related to hydrocarbons in drinking water. Access on 16th June, 2019 from: www.ezinearticles.com/Health-Concerns-Related-to-Hydrocarbons-in-DrinkingWater.

Rosalie, M. O., Thomas, J. P., Nicole, M. S. and Kathleen, M. S. (2020). Remediation in developing countries: A review of previously implemented projects and analysis of stakeholder participation efforts. *Critical Reviews in Environmental Science and Technology*, DOI: 10.1080/10643389.2020.1755203.

Shweta, J. and Pratyoosh, S. (2020). Alternative Strategies for Microbial Remediation of Pollutants via Synthetic Biology. *Frontiers in Microbiology*, 11(808), 1-14.

Singh, H. (2006). Mycoremediation: Fungal Bioremediation. Atlanta, Georgia. John Wiley and Sons Publications. Accessed on 22nd July, 2019 from: www.wiley.com/en-ng/Mycoremediation:/Fungal/Bioremediation-p-9780471755012.

Singh, S. N., Kumari, B. and Shweta, M. (2012). Microbial Degradation of Alkanes. In: *Microbial Degradation of Xenobiotics*. Edited by S. N. Singh. *Environmental Science and Engineering*, Berlin Heidelberg, Springer-Verlag. Pp. 1-34.

Sørensen, L., Sørhus, E., Nordtug, T., Incardona, J. P. and Linbo, T. L. (2017). Oil droplet fouling and differential toxicokinetics of polycyclic aromatic hydrocarbons in embryos of Atlantic haddock and Cod. *Public Library of Science One*, 12(7), e0180048.

Sylvia, A. (2019). Introduction of Petroleum Hydrocarbons Contaminants and its Human Effects. *Journal of Environmental Science and Public Health*, 3(1), 1-9.

United Nations Environment Programme, UNEP (2011). Environmental Assessment of Ogoniland. Pp 10. Retrieved on 14th June, 2018 from: www.unep.org.

United Nations Environment Programme (UNEP). (2014). No Progress: An Evaluation of the Implementation of UNEP's Environmental Assessment of Ogoniland, three years on. Accessed on 7th December, 2019 from: www.unep.org/noprogress.

United States Environmental Protection Agency, USEPA (2017). Land and Emergency Management 5401R: How to Evaluate Alternative Cleanup Technologies for Underground Storage Tank Sites. A Guide for Corrective Action Plan Reviewers. Accessed on 24th May, 2022 from: www.epa.gov/ust.

United States Naval Facilities Engineering Service Centre, NFESC. (2017). Biocell application guidance. Technical Report TDS-2017-ENV (2nd Revision). Accessed on 24th May, 2022 from: www.frtr.gov/costperformance/NFESC_Biocell_PortHueneme.

Urum, K. and Pekdemir, T. (2004) Evaluation of biosurfactants for crude oil contaminated soil washing. *Chemosphere*, 57(9), 1139-1150.

Waller, R. E. (1994). Sixty (60) years of Chemical Carcinogens: Sir Ernest Kennaway in Retirement. *Journal of Royal Society of Medicine*, 96.

Wang, X. B., Chi-Qiao, C., Nie, Y., Tang-Qin, Y., Tan, Y., Wu, G., Wu, X. L. (2011). Degradation of petroleum hydrocarbons (C_6–C_{40}) and crude oil by a novel Dietzia strain. *Bioresources Technology*, 102, 7755–7761.

Wasoh, H., Veeraswamy, K., Gunasekaran, B. and Shukor, M. Y. (2019). Biodegradation of hydrocarbon sludge by Pseudomonas sp. strain UPM-KV. *Journal of Environmental Microbiology and Toxicology*, 7, 10–15.

Wegwu, M., Uwakwe, A. and Anabi, M. (2010). Efficacy of Enhanced Natural Attenuation (Land Farming) technique in the remediation of crude oil-polluted agricultural land. *Archives of Applied Science Research*, 2(2), 431-442.

Yedil, E., Umirzak, D., Bagdat, T., Gulzipa, N., Aynur, S., Karlygash, K., Galiya, I. and Nurlan, Y. (2020). Crude Oil Contaminated Soil: Its Neutralization and Use. *Sustainability*, 12, 3087.

Zeiger, E. (2006). The Effects of Air Pollution on Plants. A Companion to Plant Physiology. 4th Ed. Accessed on 25th May, 2019 from www.4e.plantphys.net/article.php.